NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 2094

STRESS-STRAIN AND ELONGATION GRAPHS FOR ALCLAD ALUMINUM-ALLOY 24S-T86 SHEET

By James A. Miller

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SUMMARY

Results of tests on duplicate longitudinal and transverse specimens of Alclad aluminum-alloy 24S-T86 sheets with nominal thicknesses of 0.032, 0.064, and 0.125 inch are presented in the following form:

Tensile and compressive stress-strain graphs and stress-deviation graphs to a strain of about 1 percent

Stress-strain graphs for tensile specimens tested to failure

Graphs of local elongation and of elongation against gage length for tensile specimens tested to fracture

The stress-strain and stress-deviation graphs are plotted on a dimensionless basis to make them applicable to sheets of this alloy with yield strengths which differ from those of the test specimens.

INTRODUCTION

The present report is the sixth of a series presenting data on high-strength aluminum-alloy sheet (references 1 to 5). The data are presented in tables and graphs. Graphs of tangent modulus against stress and other graphs for estimating plastic buckling stress have been omitted in this report since the effect of the soft cladding material in this respect is much greater than the average effect in axial loading. (See reference 6.) Some of the graphs are presented in dimensionless form to make them applicable to sheets of this alloy with yield strengths which differ from those of the test specimens. All data are given for duplicate specimens.

The report gives the results of tests on Alclad aluminum-alloy 24S-T86 sheet, in thicknesses of 0.032, 0.064, and 0.125 inch, obtained from the Aluminum Company of America.

The author expresses his appreciation to Mrs. P. V. Jacobs who assisted in the testing and in the preparation of the graphs.

This investigation was conducted at the National Bureau of Standards under the sponsorship and with the financial assistance of the National Advisory Committee for Aeronautics.

MATERIAL

The sheets as received from the manufacturer were designated as Alclad aluminum-alloy 24S-RT, which is now designated as Alclad aluminum-alloy 24S-T36. Part of each sheet was converted into the -T86 condition by aging at 370° F for $8\frac{1}{2}$ hours at the National Bureau of Standards to furnish the specimens for this investigation. The clad layer on each surface of the sheet had a nominal thickness of 5 percent of the total thickness for the 0.032-inch sheet and 2.5 percent of the thickness for the other two sheets.

TESTS TO DETERMINE MODULI, YIELD STRENGTHS AND STRESS-STRAIN GRAPHS

Procedure

Tensile and compressive tests were made on longitudinal (in direction of rolling) specimens and on transverse (at right angles to the direction of rolling) specimens from a sheet of each thickness. The tensile specimens were of type 5 described in reference 7. The compressive specimens were rectangular strips 0.50 inch wide by 2.25 inches long. Duplicate specimens of each kind were tested in a beam-and-poise, screw-type, testing machine of 50-kip capacity with the use of the poise for the 5-kip range. The tensile specimens were held in Templin grips. The compressive specimens were loaded between hardened-steel bearing blocks in the subpress described in reference 8. Lateral support against premature buckling was furnished by lubricated solid guides, as described in reference 9. The strain was measured with a pair of Tuckerman 1-inch optical strain gages attached to the sheet faces of the tensile specimens and attached to the edge faces of the compressive specimens. The rate of loading was about 2 ksi per minute.

Results

The results of the tensile and compressive tests are given in table 1. Each value of Young's modulus in the table was taken as the slope of a least-squares straight line fitted to the stress-strain curve at stresses below the point where the cladding started to yield. It was based on 4 times the number of points shown on the graph for that portion of the curve. The yield strengths determined by the offset method were obtained from the stress-strain curves and the experimental values of Young's modulus. The yield strengths determined by the secant method were obtained from the stress-strain curves and values of secant modulus 0.7 and 0.85 times the experimental values of Young's modulus.

Stress-Strain Graphs

The stress-strain graphs are plotted in dimensionless form in figures 1 to 6. The coordinates σ and ϵ in these graphs are defined by

$$\sigma = \frac{s}{s_1}$$

$$\epsilon = \frac{eE}{s_1}$$

where

s stress corresponding to strain e

s_1 secant yield strength (0.7E)

E Young's modulus

Composite dimensionless stress-strain graphs which show the bands within which the data fall for tests of a given kind and a given direction in the sheet are shown in figures 7 and 8. The maximum width of band in terms of σ is less than 0.02. Each band represents data for six specimens; the widths might have been greater if tests had been made on a larger number of specimens. Part of the deviation of the curves from affinity may be attributed to experimental variation in the values of Young's modulus which were obtained from a relatively small region of each curve, and part may be attributed to differences in the percentage of cladding of the 0.032-inch sheet and of the other two sheets.

Stress-Deviation Graphs

Dimensionless stress-deviation graphs are shown in figures 9 to 14. The ordinates are the same as those used for the stress-strain graphs. The abscissas are the corresponding values of $\delta = \epsilon - \sigma$. All of the curves intersect at the point $\sigma = 1$, $\delta = 3/7$, which corresponds to the secant yield strength (0.7E). This point is indicated on the graphs by a short vertical line.

The graphs were plotted on log-log paper to indicate which portion of the stress-strain curves can be represented by the analytical expression given in reference 10:

$$e = \frac{s}{E} + K\left(\frac{s}{E}\right)^n$$

This expression holds where the plot of deviation against stress on logarithmic paper follows a straight line. (See reference 10.) Actually each graph has a pronounced knee. This is caused, in part, by the large deviations at low stresses as a result of yielding of the cladding material. It follows that the stress-strain graphs of the sheets cannot be accurately represented by a single analytical expression of the foregoing type. The graphs can be approximated, except for a rather large transition region, by two straight lines represented by two equations of the above type with different sets of the constants K and n. Only the graphs for transverse compression show good agreement with a straight line for values of $s/s_1 > s_2/s_1$, where s_2 is the secant yield strength (0.85E); values of s_2/s_1 are shown in each figure. Table 1 gives values of s_1/s_2 for all specimens to indicate the sharpness of the knee of the stress-strain curve and for obtaining an average value of the shape parameter n as shown in reference 10.

TENSILE STRESS-STRAIN TESTS TO FAILURE

Procedure

Tensile tests to failure were made on two longitudinal and two transverse specimens from a sheet of each thickness. The specimens were of type 5 described in reference 7. The tests were made in fluid-support, Bourdon tube, hydraulic testing machines having Tate-Emery load indicators. The specimens were held in Templin grips. They were tested at a cross-head speed of about 0.1 inch per minute. Autographic load-extension curves were obtained with a Templin type stress-strain recorder by using a Peters averaging total-elongation extensometer with a 2-inch gage length and a magnification factor of 50. Stresses based on the original cross section and the corresponding strains based on the original gage length were determined from these curves. The data for the portion at and beyond the knee of each curve were combined with stress-strain data on duplicate specimens on which strain up to the knee of the curve had been measured with Tuckerman optical strain gages.

Stress-Strain Graphs

The resulting stress-strain curves are shown in figures 15 to 17. Values of tensile strength and of elongation in 2 inches are given in the tables in each figure. The values of elongation usually corresponded to a strain of about 0.006 less than the maximum recorded strain under load.

LOCAL-ELONGATION TESTS

Procedure

Photogrid measurements (reference 11) were made on two longitudinal and two transverse tensile specimens from a sheet of each thickness. The specimens were of type 5 described in reference 7. The photogrid negative was made from the master grid described in reference 1. The specimens were coated with cold top enamel. This has been found to be less critical with respect to exposure time than the photoengraving glue mentioned in reference 11. The prints were also usually easier to measure near the fracture. The specimens were held in Templin grips and were fractured in a testing machine at a cross-head speed of about 0.1 inch per minute. Measurements of grid spacing were made by the technique described in reference 1, except that a measuring engine having a microscope with magnification of about 100 diameters was used. The instrument was read to 0.001 millimeter (1 division on the barrel).

Graphs

The local elongations in percent of the original spacing, plotted against the distance before test from one end of the gage length, are shown in figures 18 to 23. The fracture in each case occurred in the grid spacing in which the greatest elongation took place.

Various gage lengths which in every case included the fracture were measured and the percentage elongations in terms of the original gage lengths were computed. The relationships between these elongations and the gage lengths are shown in figures 24 to 29. The gage lengths were plotted to a logarithmic scale to present a large range of values on a single graph.

National Bureau of Standards
Washington, D. C., October 20, 1948

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TABLE 1.- RESULTS OF TENSILE AND COMPRESSIVE TESTS ON ALCLAD ALUMINUM-ALLOY 24S-T86 SHEET

Specimen	Test	Direction	Thickness (in.)	Young's modulus, E (ksi)	Yield strength: Offset method (Offset = 0.2 percent) (ksi)	Yield strength: Secant method s_1 (0.7E) (ksi)	Yield strength: Secant method s_2 (0.85E) (ksi)	s_1/s_2	Tensile strength (ksi)	Elongation in 2 in. (percent)
032-T1L	Tensile	Longitudinal	0.0330	10,680	72.6	73.0	71.5	1.021	75.0	5.0
032-T2L	----do-----	-----do-----	.0330	10,680	72.7	73.1	71.6	1.021	75.6	5.5
032-T1T	----do-----	Transverse	.0331	10,630	70.2	71.1	67.5	1.053	73.6	4.0
032-T2T	----do-----	-----do-----	.0331	10,640	69.7	70.6	66.9	1.055	73.8	5.5
032-C1L	Compressive	Longitudinal	.0331	10,680	73.0	74.5	70.5	1.057	----	---
032-C2L	----do-----	-----do-----	.0331	10,710	73.3	74.7	70.8	1.055	----	---
032-C1T	----do-----	Transverse	.0331	10,640	74.2	75.3	72.4	1.039	----	---
032-C2T	----do-----	-----do-----	.0332	10,680	73.5	74.6	71.8	1.039	----	---
064-T1L	Tensile	Longitudinal	.0644	10,700	73.8	74.1	73.2	1.013	76.3	6.5
064-T2L	----do-----	-----do-----	.0645	10,740	73.8	74.1	73.1	1.014	76.5	6.0
064-T1T	----do-----	Transverse	.0643	10,770	70.5	71.3	68.3	1.044	74.8	5.5
064-T2T	----do-----	-----do-----	.0646	10,720	70.7	71.6	68.7	1.043	74.9	5.5
064-C1L	Compressive	Longitudinal	.0646	10,820	73.2	74.5	71.0	1.050	----	---
064-C2L	----do-----	-----do-----	.0645	10,740	72.9	74.2	70.7	1.050	----	---
064-C1T	----do-----	Transverse	.0645	10,780	74.6	75.6	73.3	1.032	----	---
064-C2T	----do-----	-----do-----	.0644	10,750	74.3	75.2	72.9	1.032	----	---
125-T1L	Tensile	Longitudinal	.1245	10,660	74.4	74.5	73.7	1.011	76.0	6.5
125-T2L	----do-----	-----do-----	.1245	10,660	74.3	74.5	73.7	1.011	76.0	7.0
125-T1T	----do-----	Transverse	.1245	10,730	71.5	72.4	69.3	1.045	75.5	6.0
125-T2T	----do-----	-----do-----	.1247	10,660	71.2	72.2	69.2	1.043	75.3	6.0
125-C1L	Compressive	Longitudinal	.1245	10,650	73.8	74.9	71.9	1.043	----	---
125-C2L	----do-----	-----do-----	.1245	10,690	73.7	74.9	71.8	1.044	----	---
125-C1T	----do-----	Transverse	.1248	10,720	75.7	76.7	74.5	1.030	----	---
125-C2T	----do-----	-----do-----	.1246	10,700	75.7	76.7	74.4	1.031	----	---

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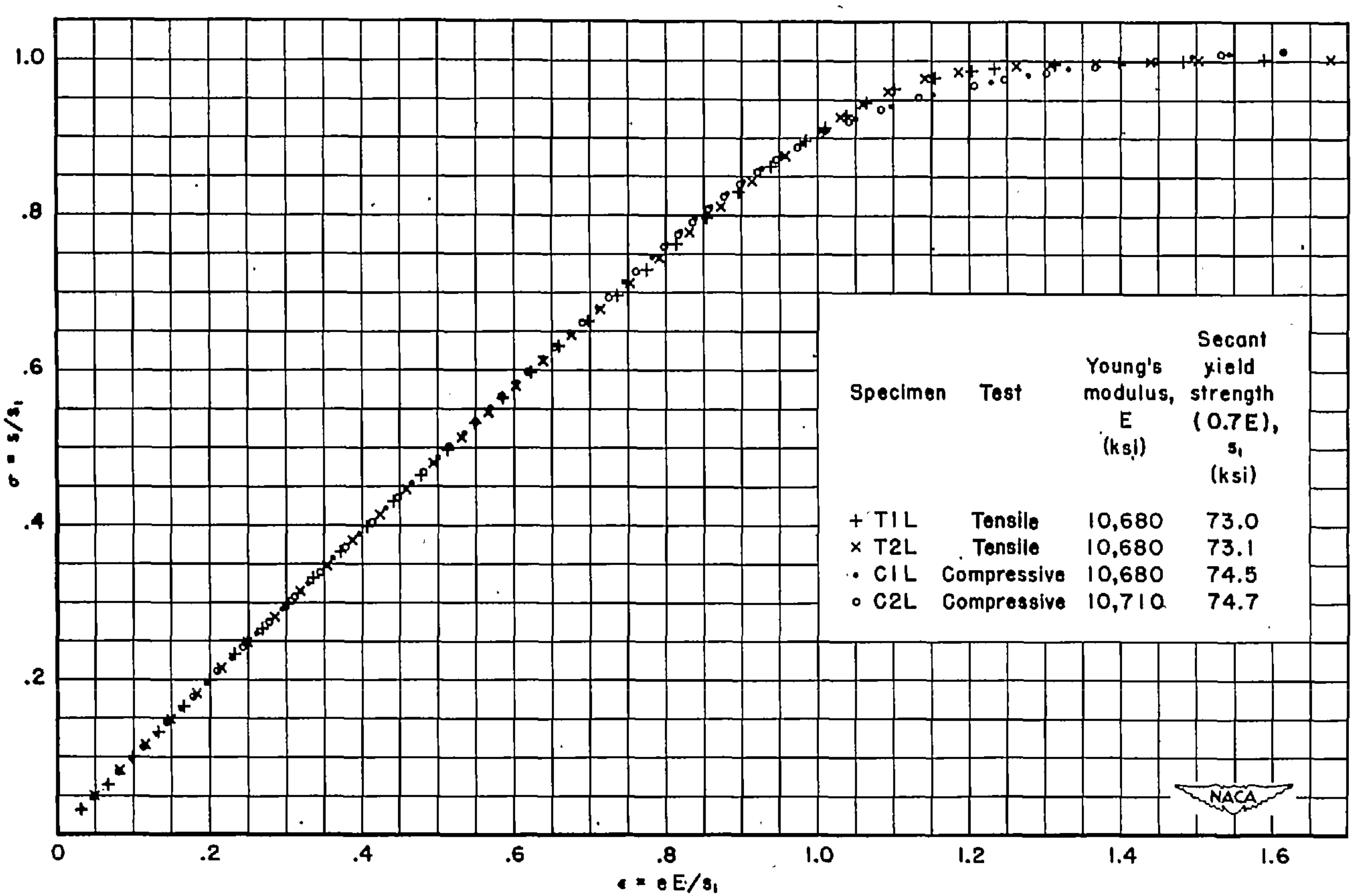

Figure 1.- Dimensionless stress-strain graphs. Alclad 24S-T86 sheet, longitudinal specimens 0.032 inch thick.

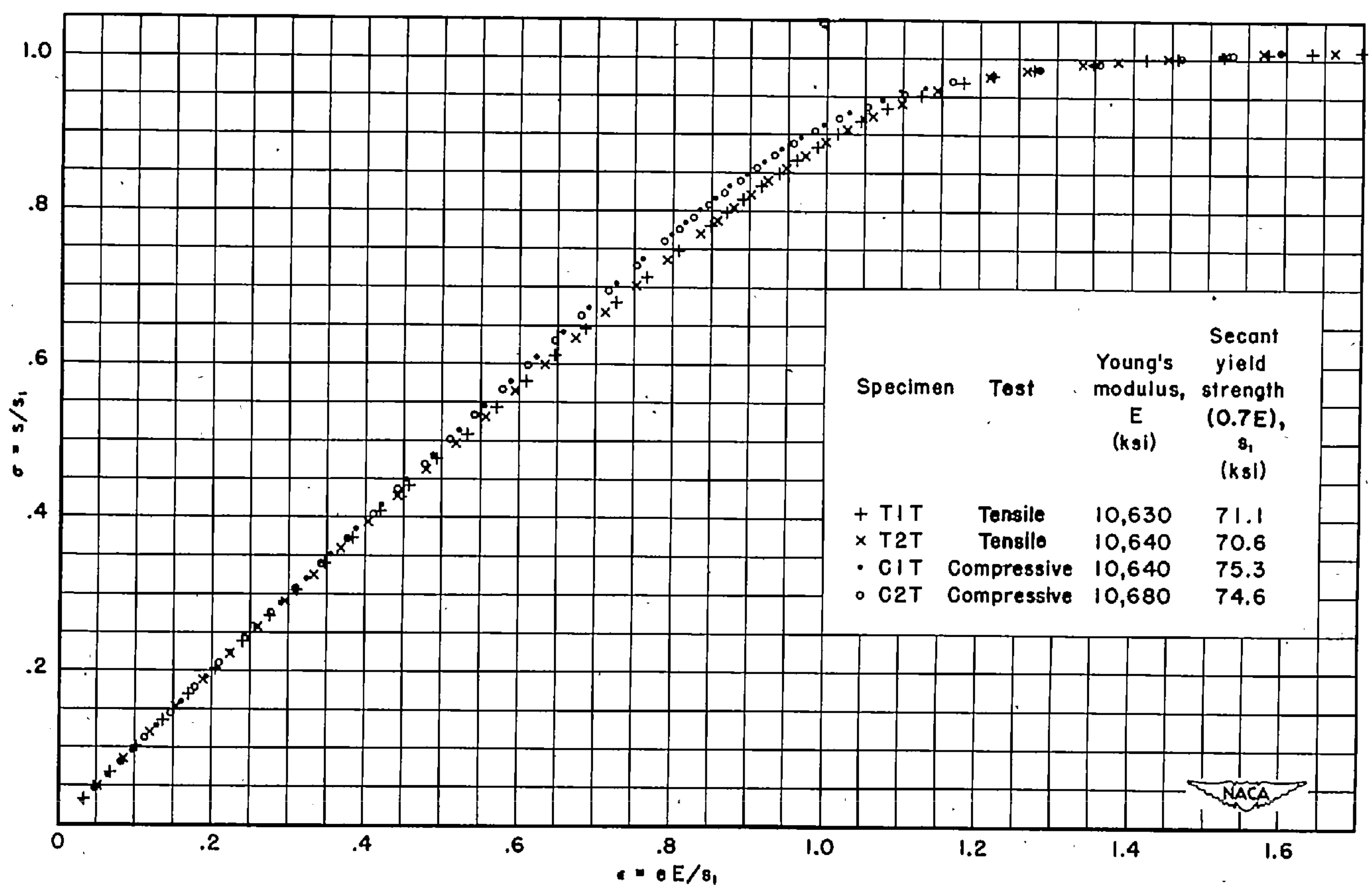

Figure 2.- Dimensionless stress-strain graphs. Alclad 24S-T86 sheet, transverse specimens 0.032 inch thick.

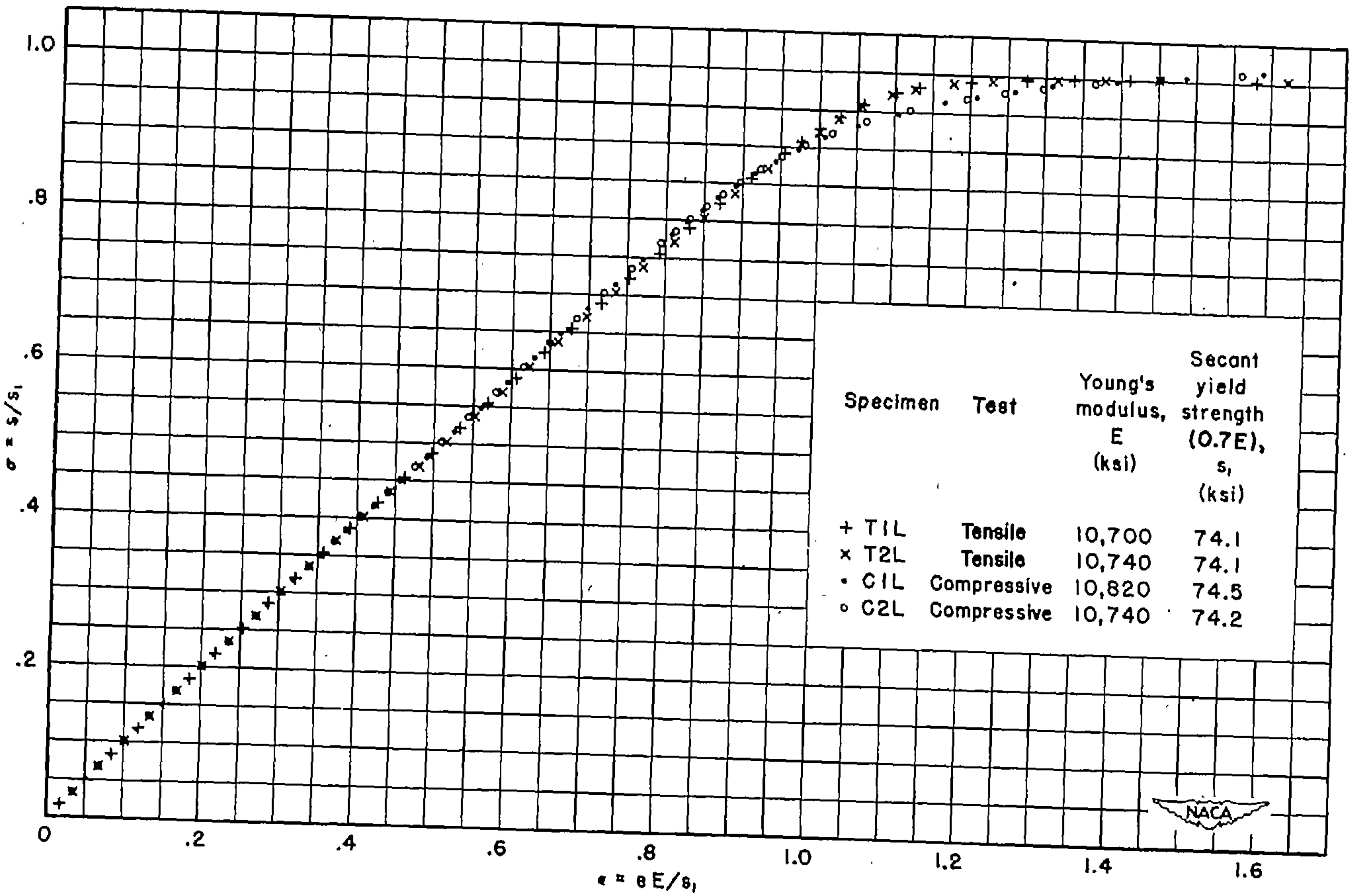

Figure 3.- Dimensionless stress-strain graphs. Alclad 24S-T86 sheet, longitudinal specimens 0.064 inch thick.

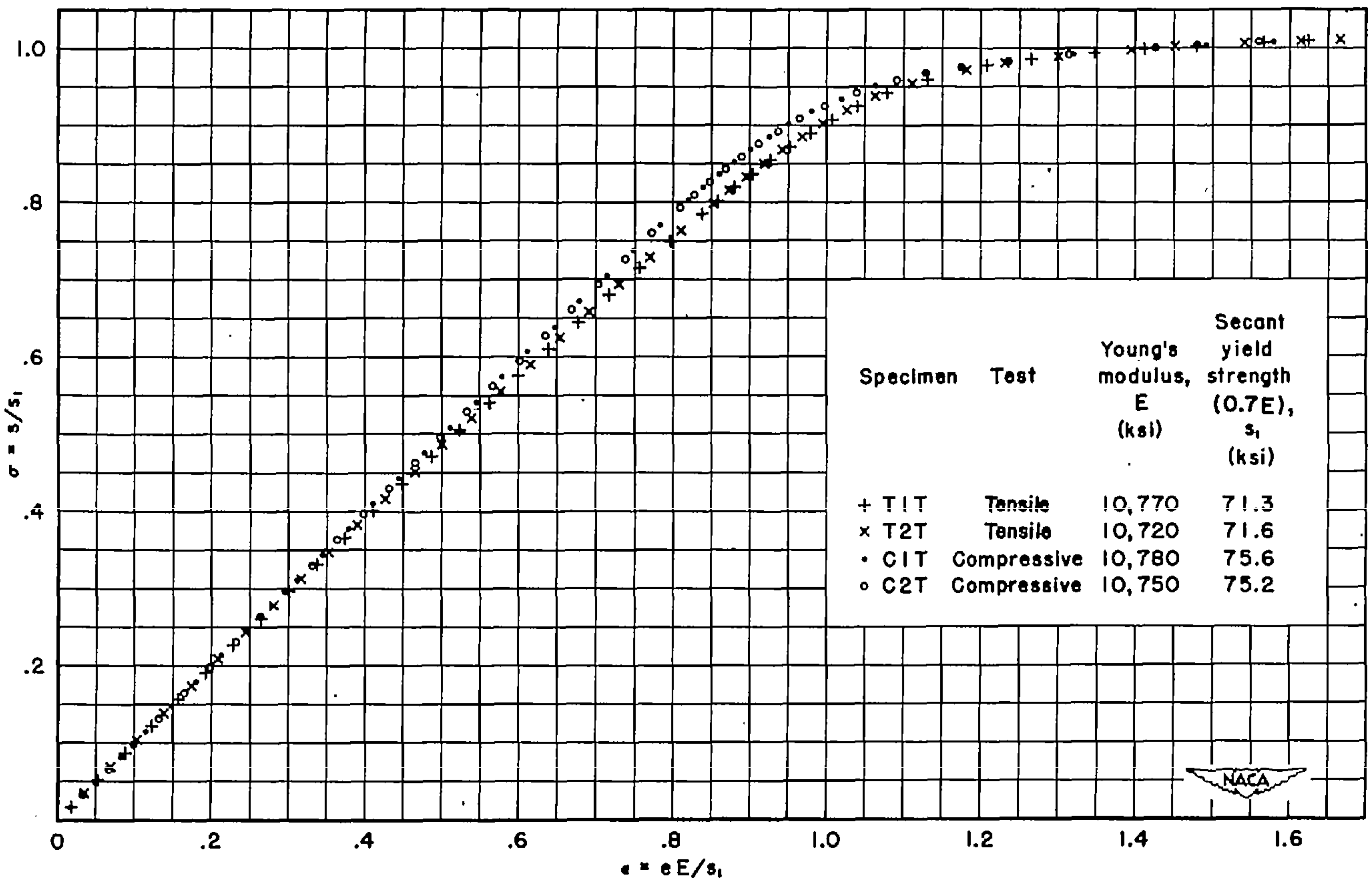

Figure 4.- Dimensionless stress-strain graphs. Alclad 24S-T86 sheet, transverse specimens 0.064 inch thick.

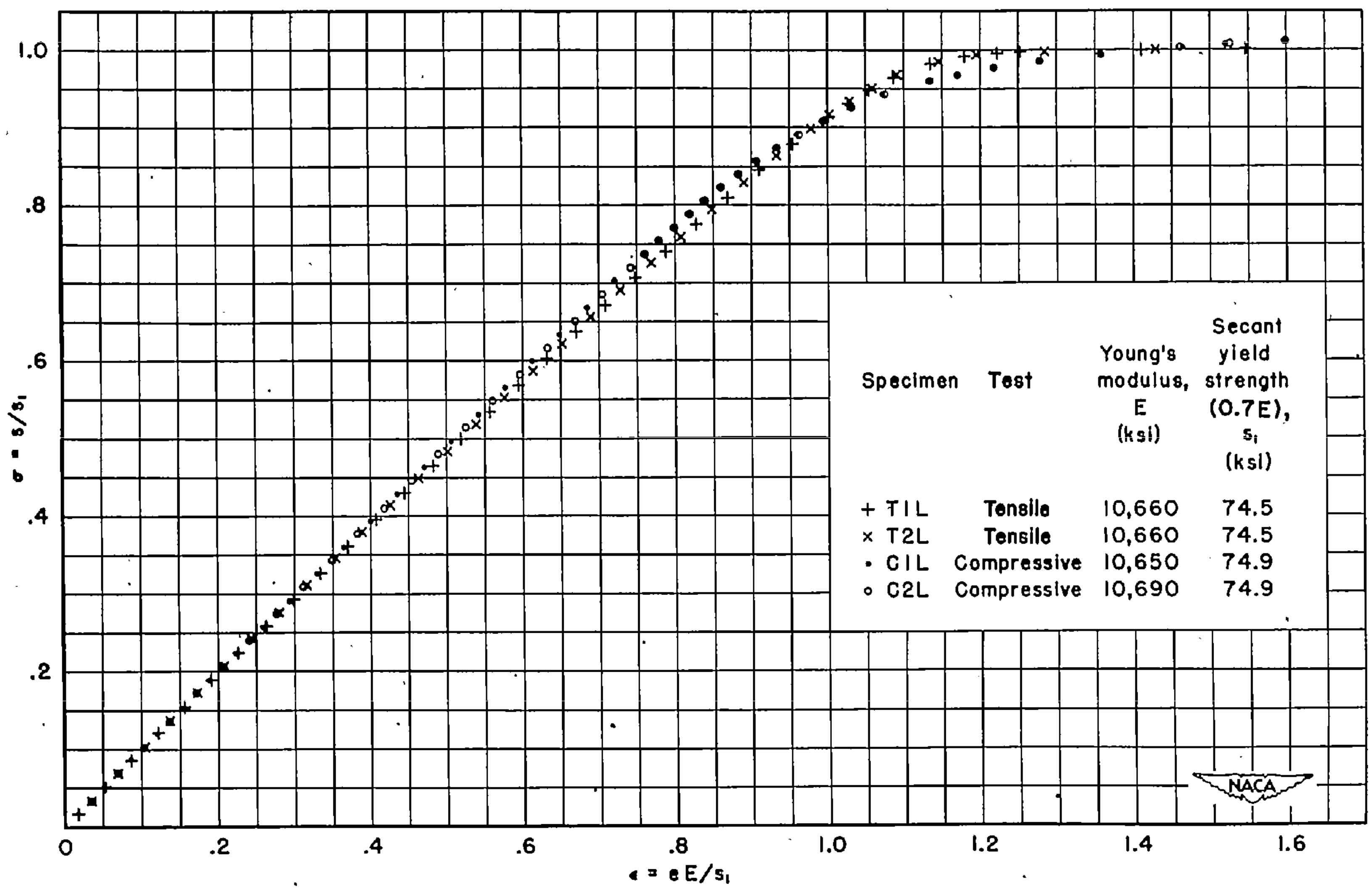

Figure 5.- Dimensionless stress-strain graphs. Alclad 24S-T86 sheet, longitudinal specimens 0.125 inch thick.

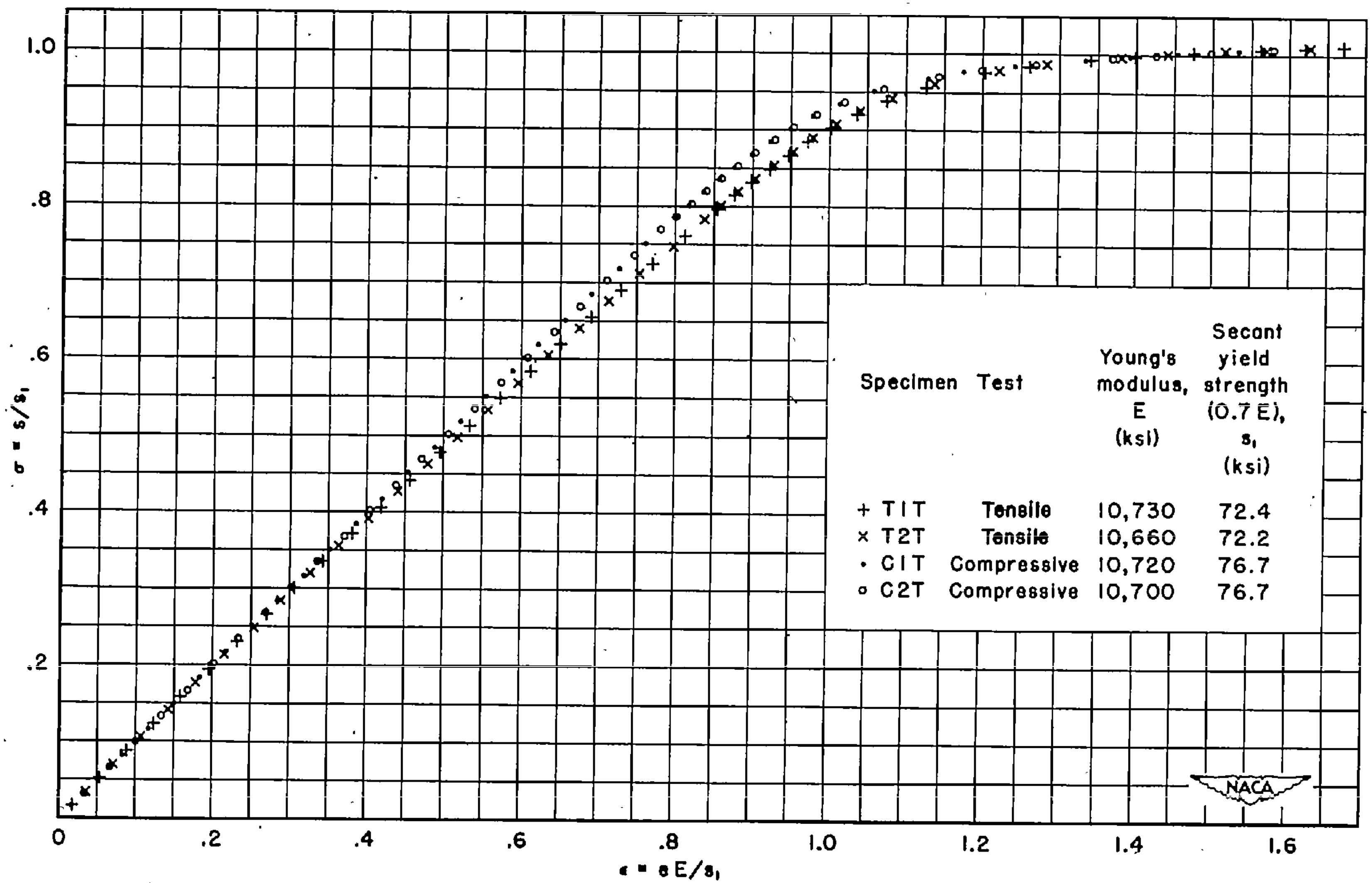

Figure 6.- Dimensionless stress-strain graphs. Alclad 24S-T86 sheet, transverse specimens 0.125 inch thick.

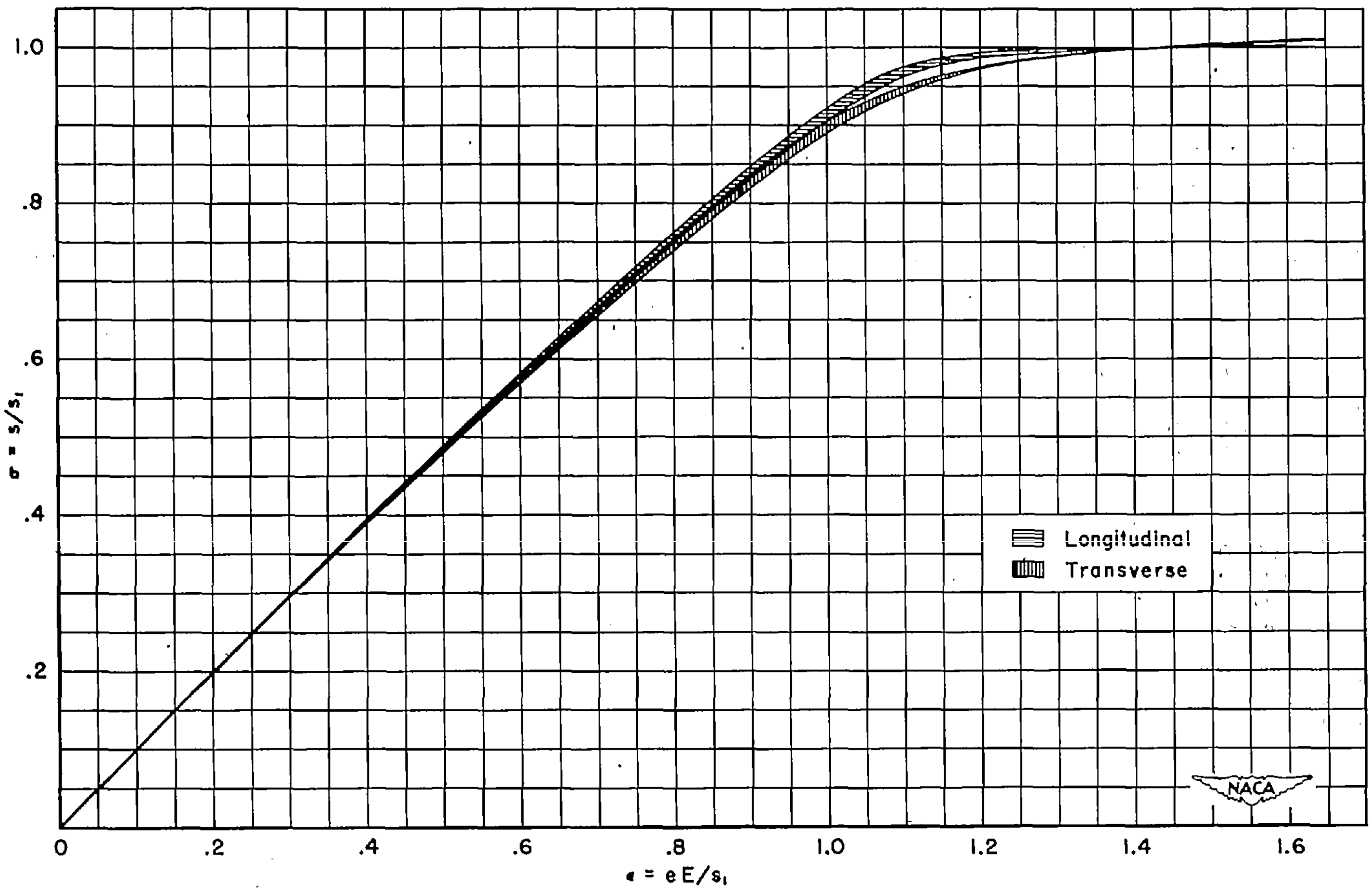

Figure 7.- Limits of dimensionless tensile stress-strain graphs. Alclad 24S-T86 sheet 0.032, 0.064, and 0.125 inch thick.

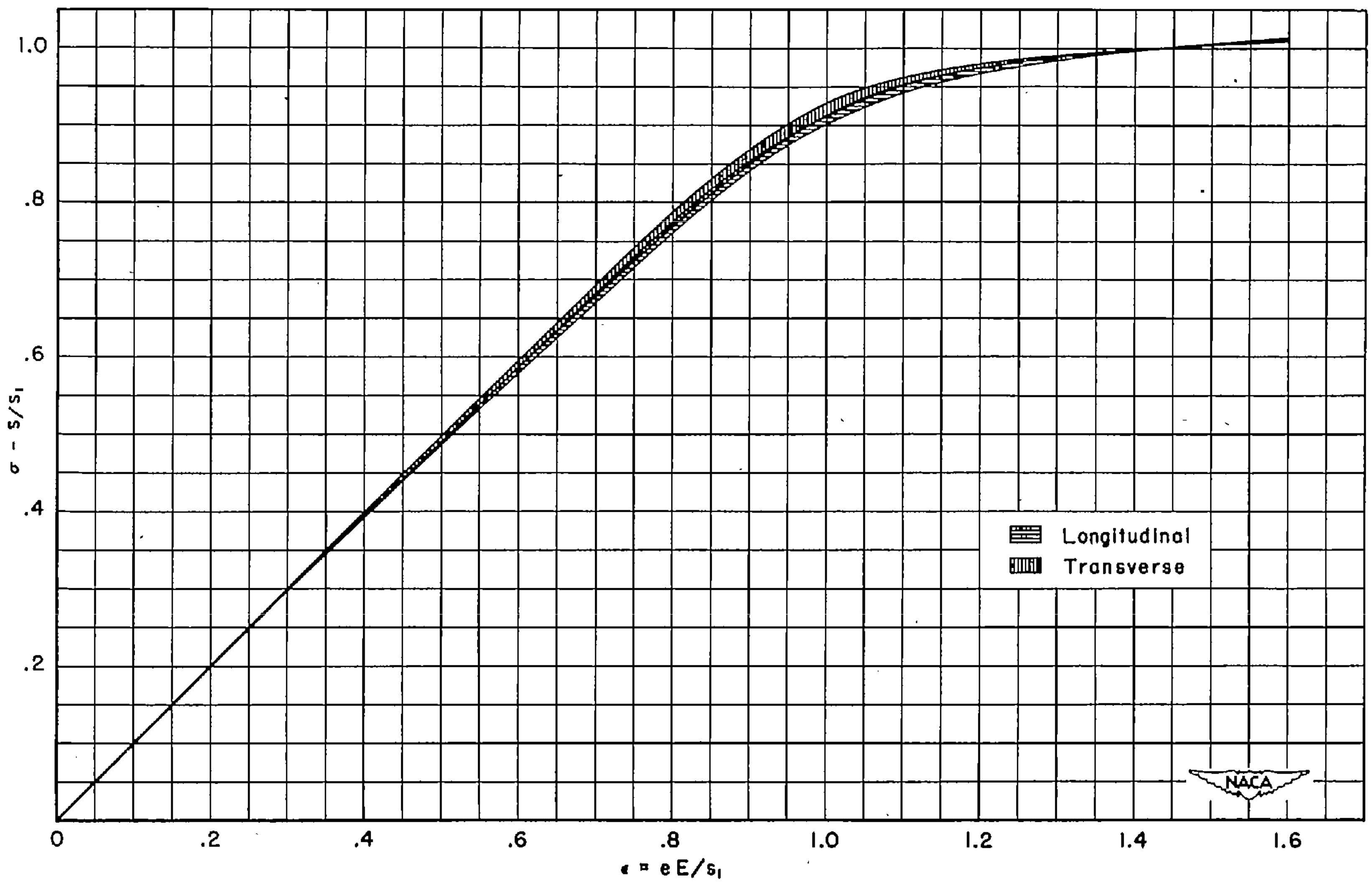

Figure 8.- Limits of dimensionless compressive stress-strain graphs. Alclad 24S-T86 sheet 0.032, 0.064, and 0.125 inch thick.

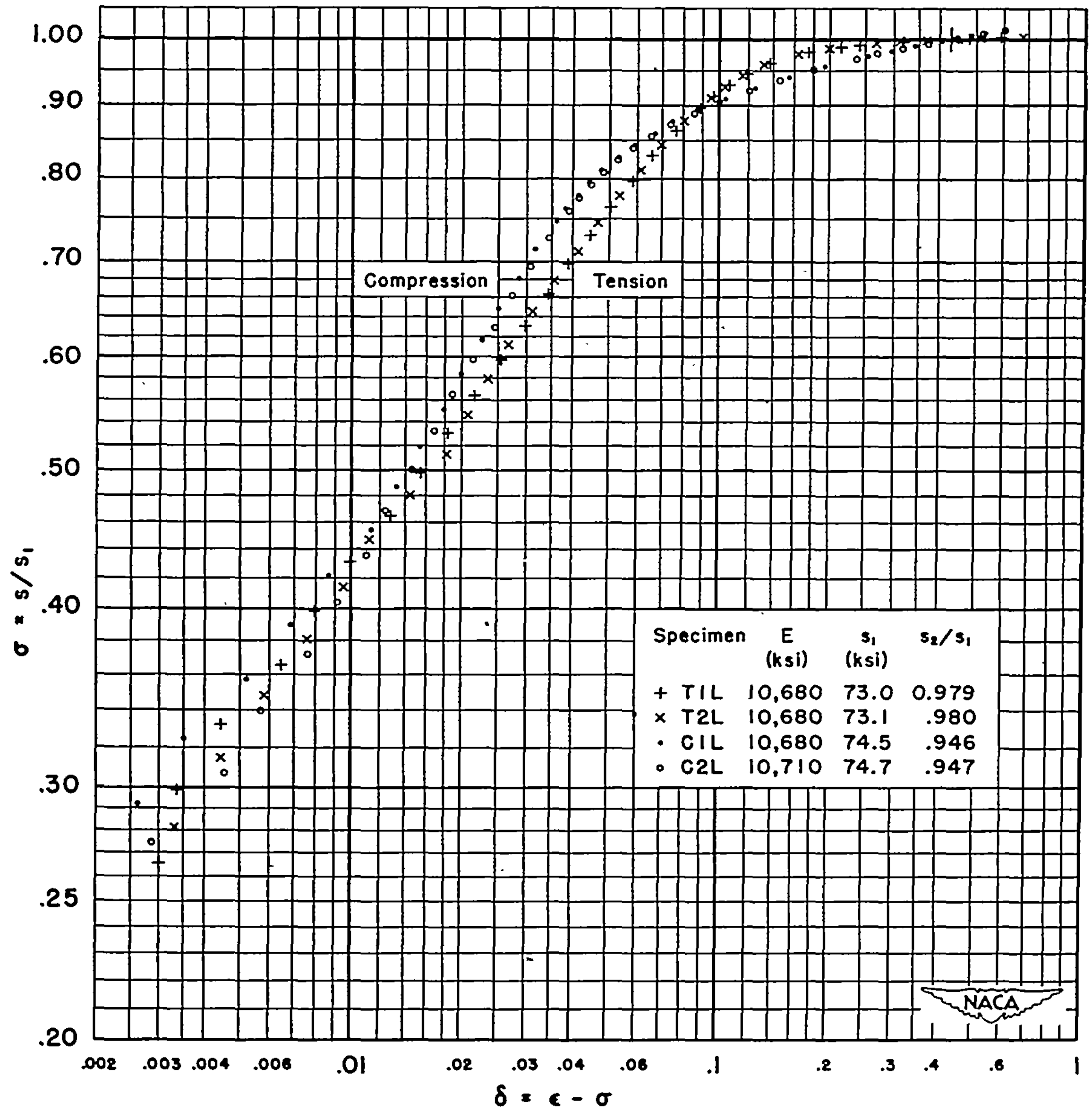

Figure 9.- Dimensionless stress-deviation graphs. Alclad 24S-T86 sheet, longitudinal specimens 0.032 inch thick. E, Young's modulus; s_1, secant yield strength (0.7E); s_2, secant yield strength (0.85E).

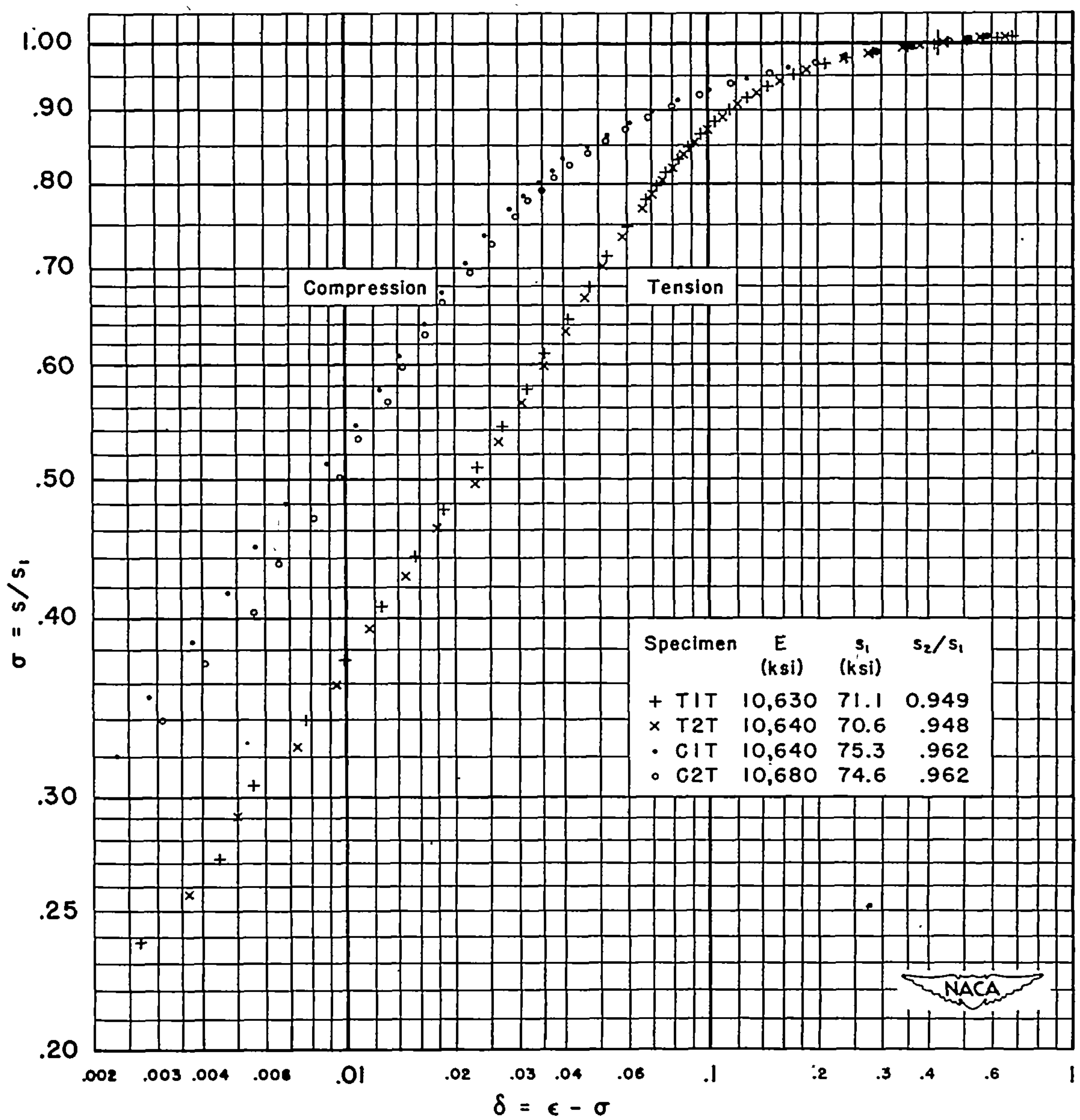

Figure 10.- Dimensionless stress-deviation graphs. Alclad 24S-T86 sheet, transverse specimens 0.032 inch thick. E, Young's modulus; s_1, secant yield strength (0.7E); s_2, secant yield strength (0.85E).

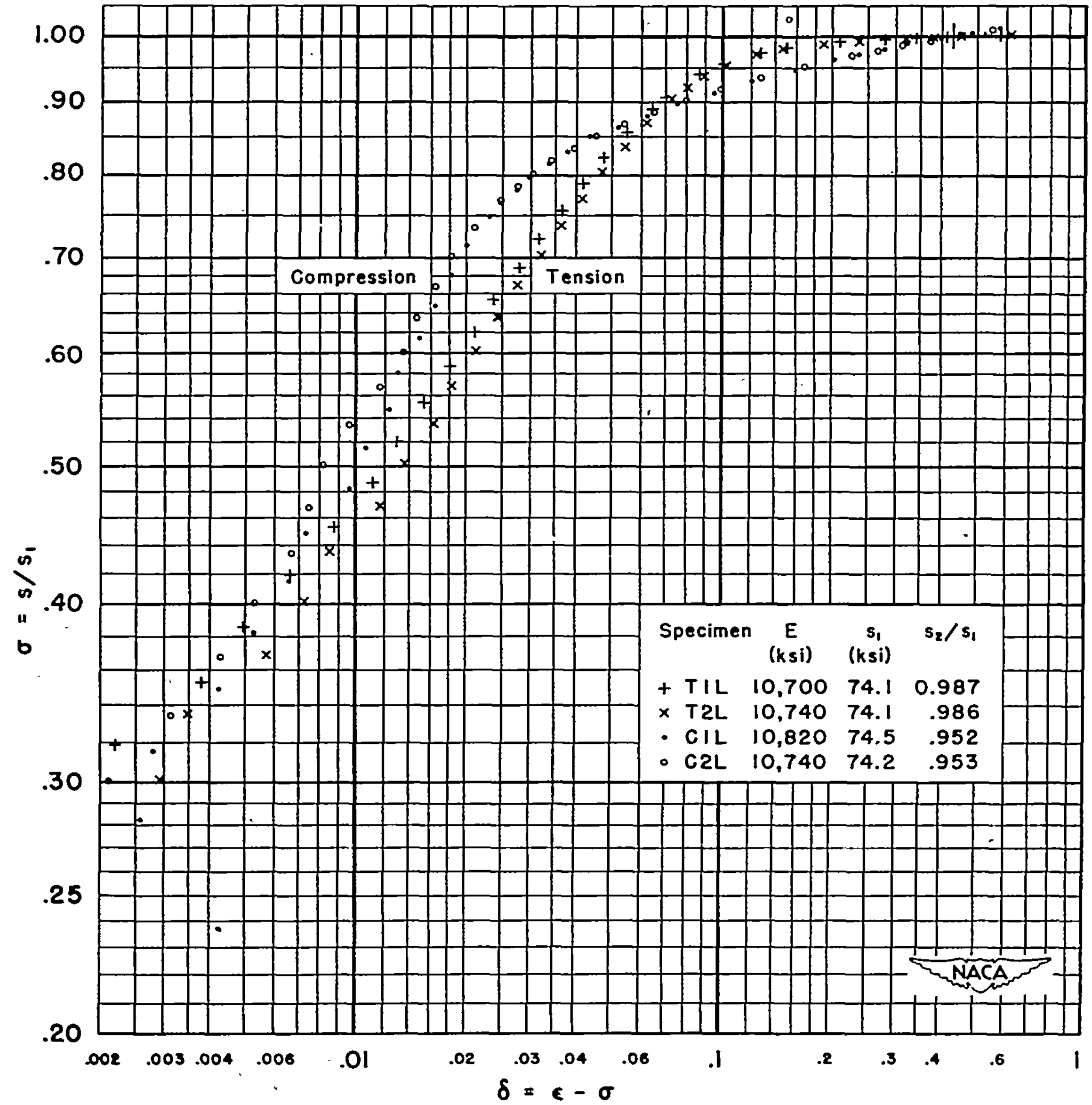

Figure 11.- Dimensionless stress-deviation graphs. Alclad 24S-T86 sheet, longitudinal specimens 0.064 inch thick. E, Young's modulus; s_1, secant yield strength (0.7E); s_2, secant yield strength (0.85E).

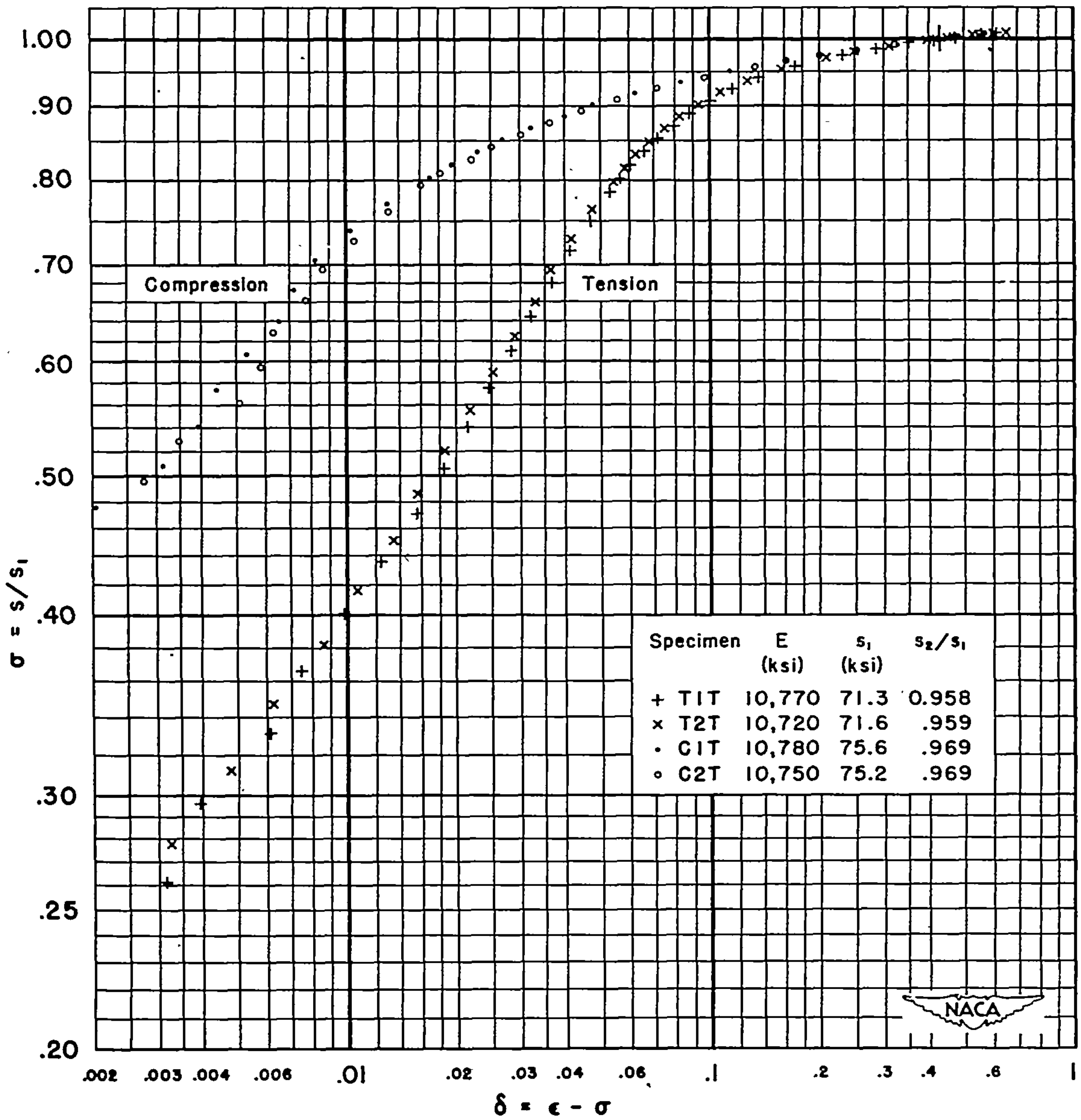

Figure 12.- Dimensionless stress-deviation graphs. Alclad 24S-T86 sheet, transverse specimens 0.064 inch thick. E, Young's modulus; s_1, secant yield strength (0.7E); s_2, secant yield strength (0.85E).

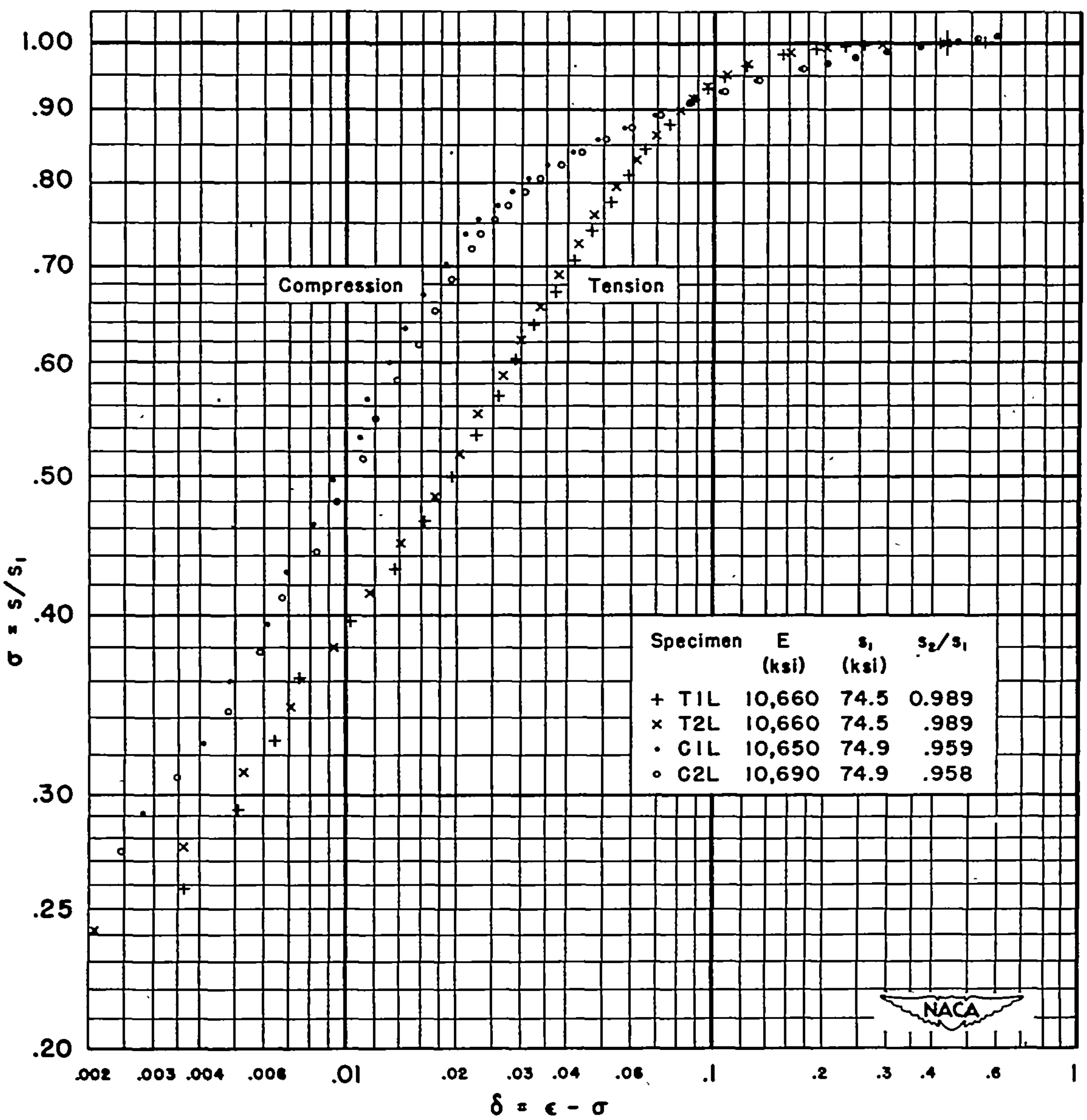

Figure 13.- Dimensionless stress-deviation graphs. Alclad 24S-T86 sheet, longitudinal specimens 0.125 inch thick. E, Young's modulus; s_1, secant yield strength (0.7E); s_2, secant yield strength (0.85E).

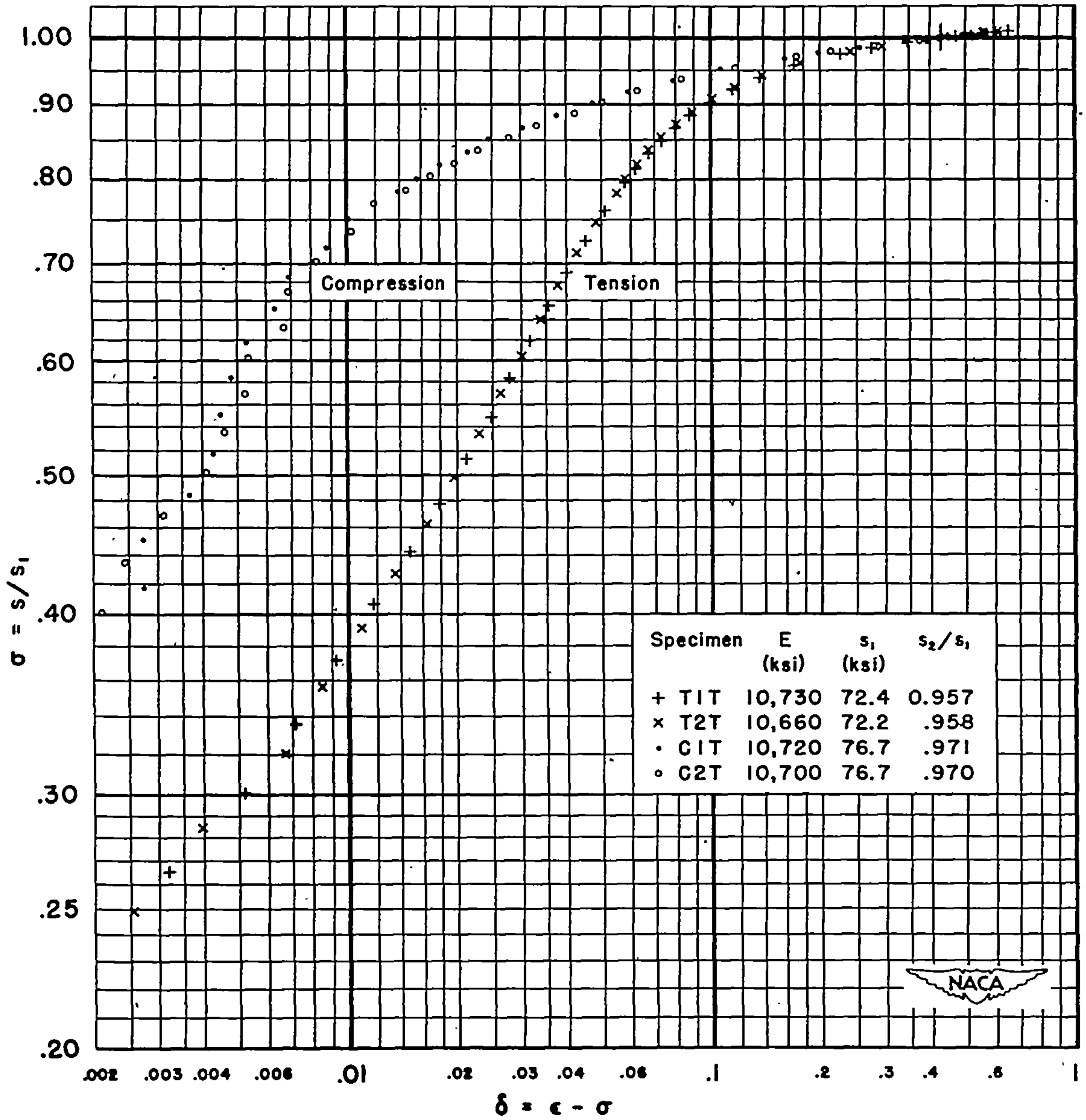

Figure 14.- Dimensionless stress-deviation graphs. Alclad 24S-T86 sheet, transverse specimens 0.125 inch thick. E, Young's modulus; s_1, secant yield strength (0.7E); s_2, secant yield strength (0.85E).

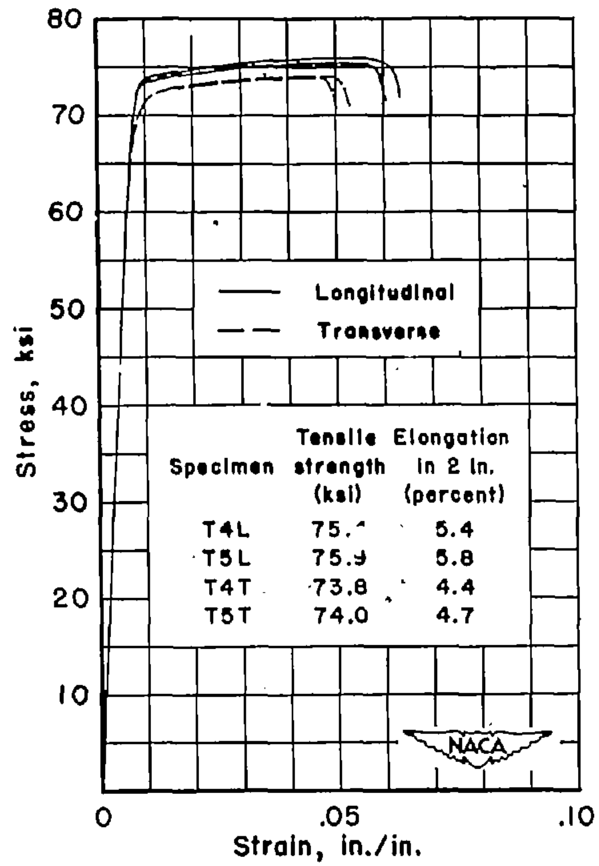

Figure 15.- Curves of tensile stress-strain tests to failure. Alclad 24S-T86 sheet 0.032 inch thick.

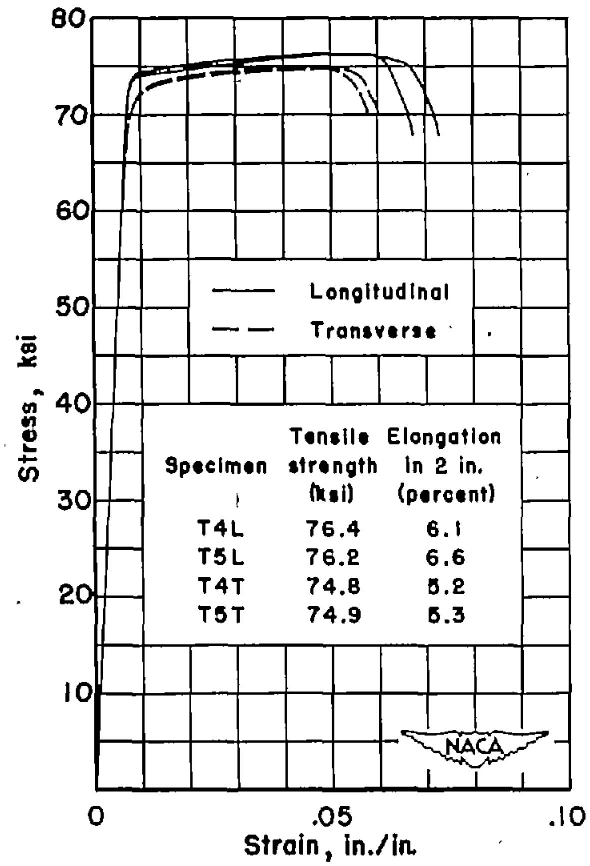

Figure 16.- Curves of tensile stress-strain tests to failure. Alclad 24S-T86 sheet 0.064 inch thick.

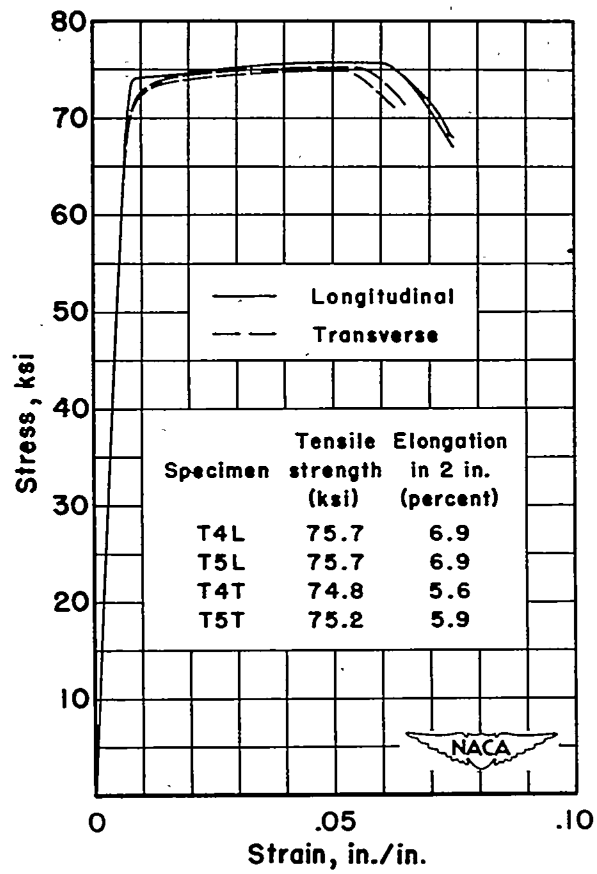

Figure 17.- Curves of tensile stress-strain tests to failure. Alclad 24S-T86 sheet 0.125 inch thick.

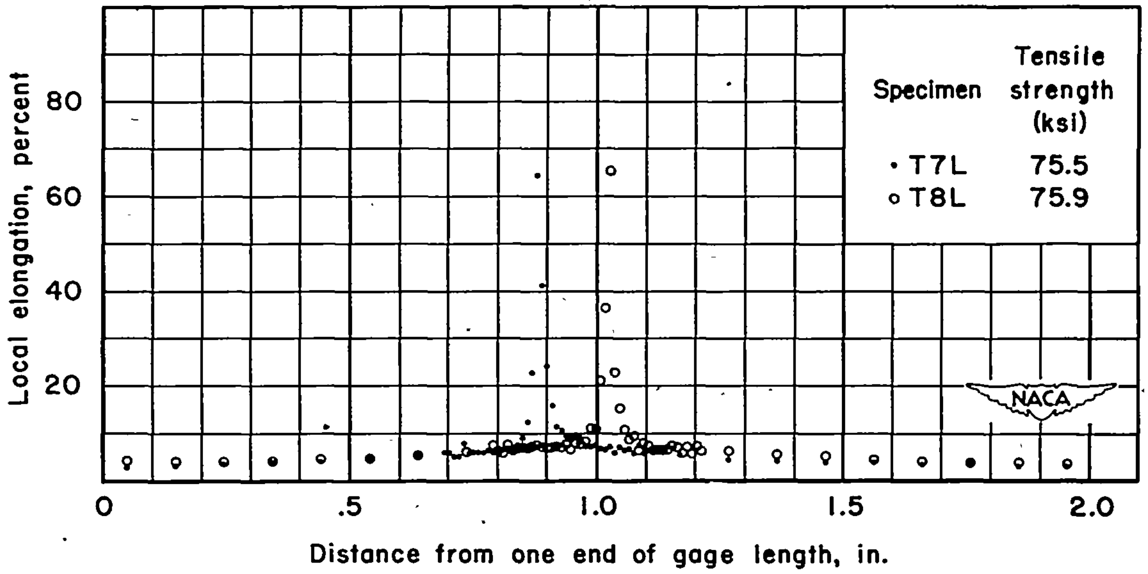

Figure 18.- Local elongation. Alclad 24S-T86 sheet, longitudinal specimens 0.032 inch thick.

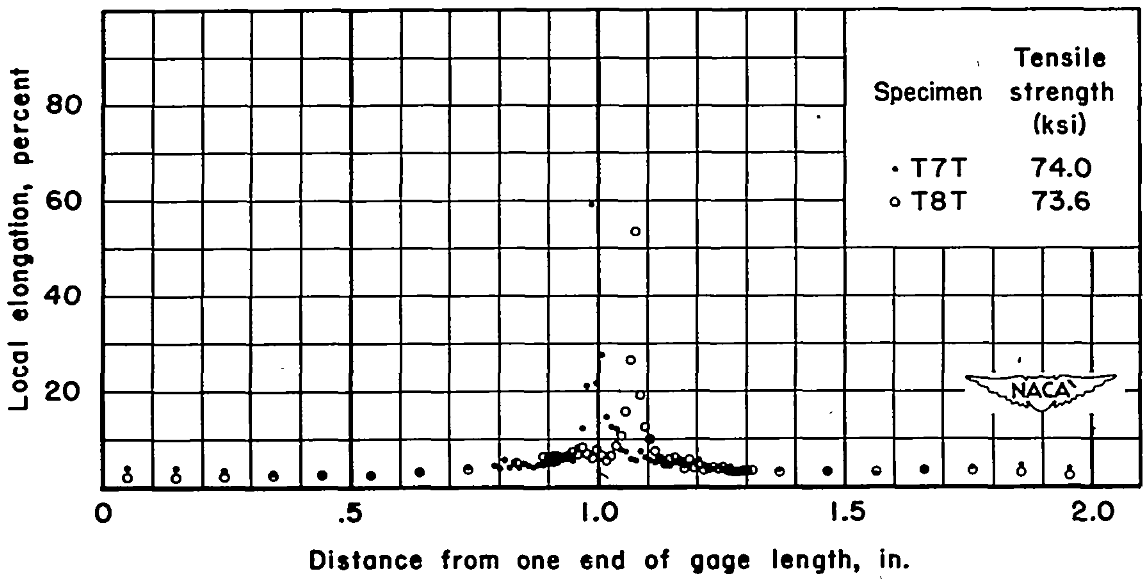

Figure 19.- Local elongation. Alclad 24S-T86 sheet, transverse specimens 0.032 inch thick.

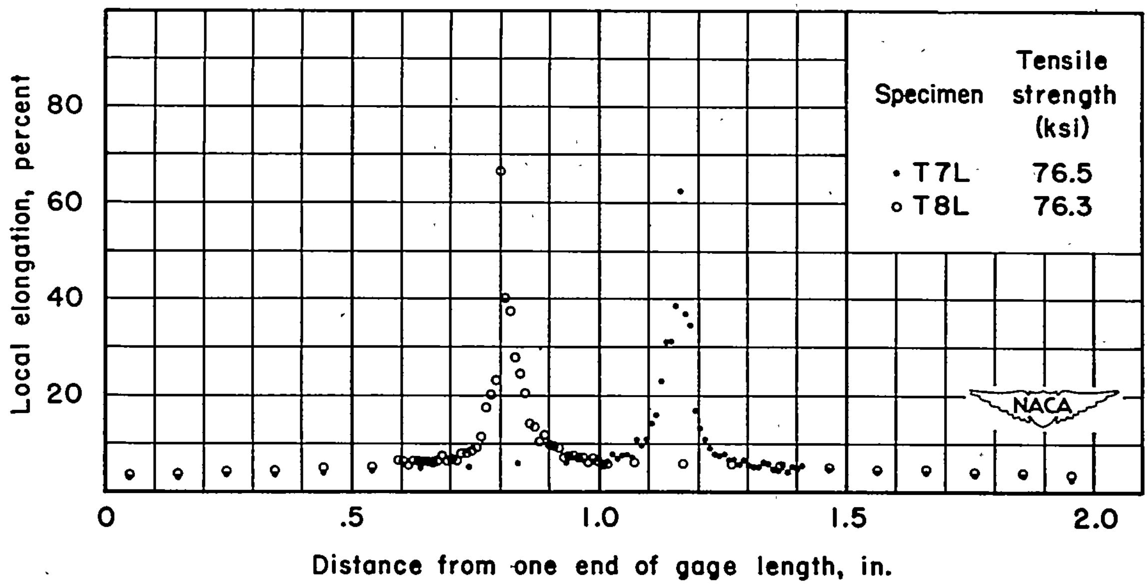

Figure 20.- Local elongation. Alclad 24S-T86 sheet, longitudinal specimens 0.064 inch thick.

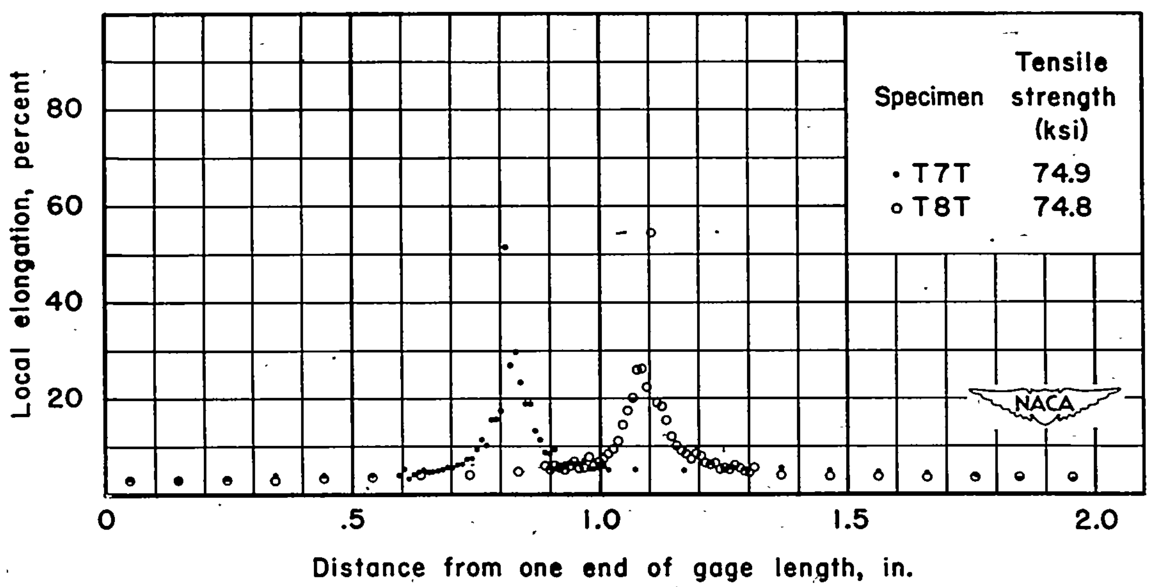

Figure 21.- Local elongation. Alclad 24S-T86 sheet, transverse specimens 0.064 inch thick.

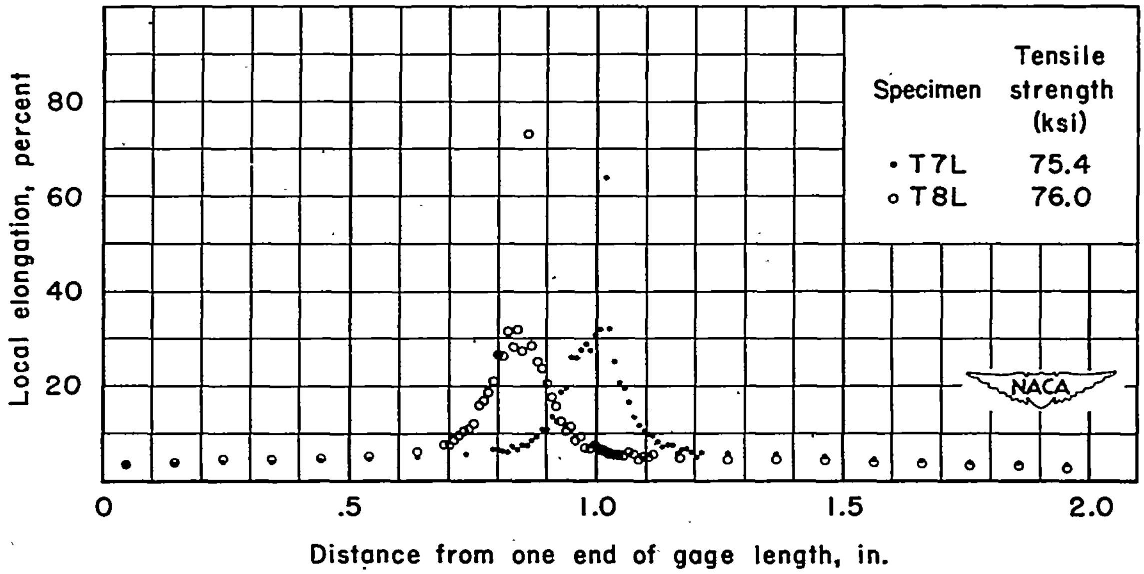

Figure 22.- Local elongation. Alclad 24S-T86 sheet, longitudinal specimens 0.125 inch thick.

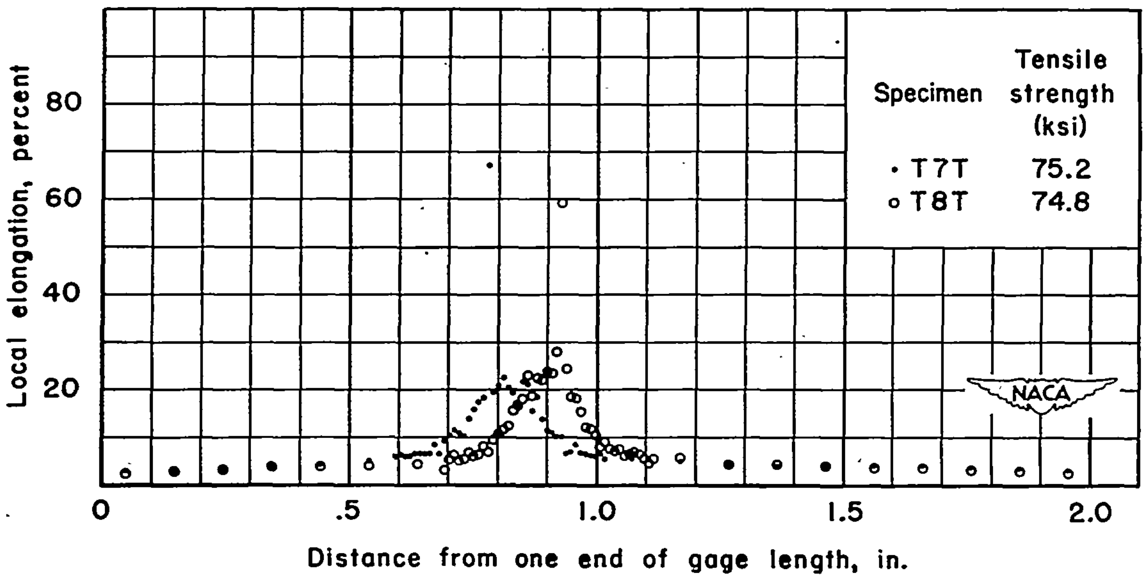

Figure 23.- Local elongation. Alclad 24S-T86 sheet, transverse specimens 0.125 inch thick.

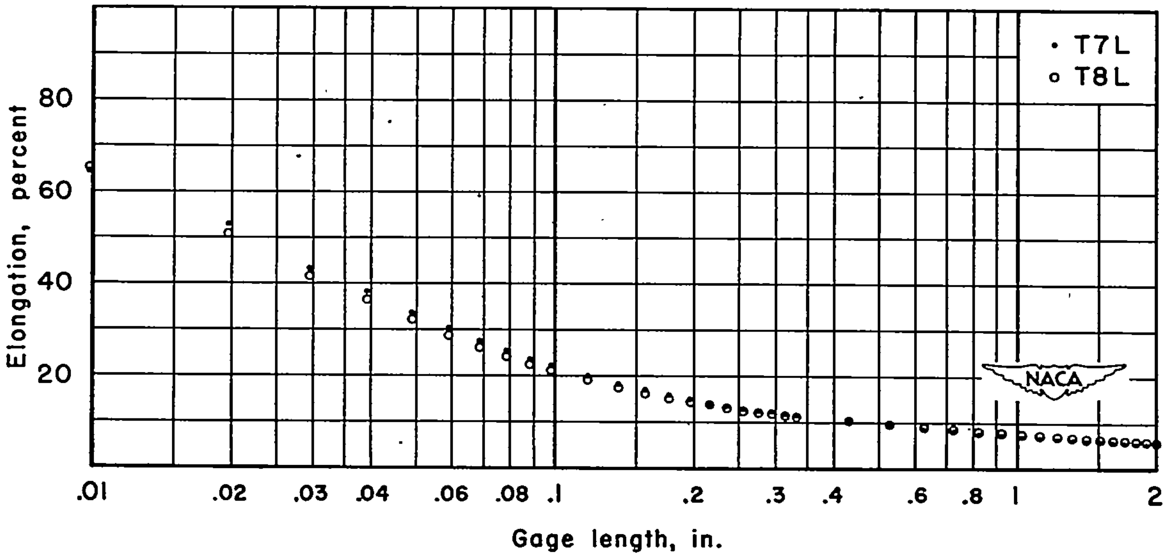

Figure 24.- Graphs of elongation against gage length. Alclad 24S-T86 sheet, longitudinal specimens 0.032 inch thick.

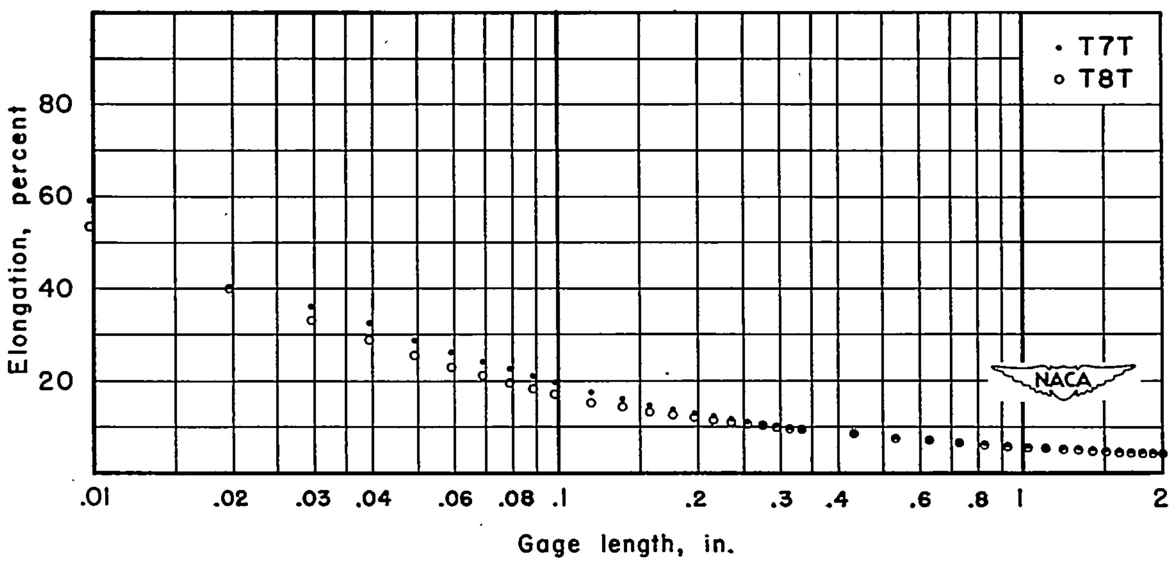

Figure 25.- Graphs of elongation against gage length. Alclad 24S-T86 sheet, transverse specimens 0.032 inch thick.